

AUTOMATIC SYSTEMS AND THE LOW-LEVEL WIND HAZARD

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ABSTRACT

Automatic flight control systems provide means for significantly enhancing survivability in severe wind hazards. The technology required to produce the necessary control algorithms is available and has been made technically feasible by the advent of digital flight control systems and accurate, low-noise sensors, especially strap-down inertial sensors. The application of this technology and these means has not generally been enabled except for automatic landing systems, and even then the potential has not been fully exploited. To fully exploit the potential of automatic systems for enhancing safety in wind hazards requires providing incentives, creating demand, inspiring competition, education, and eliminating prejudicial disincentives to overcome the economic penalties associated with the extensive and risky development and certification of these systems. If these changes will come about at all, it will likely be through changes in the regulations provided by the certifying agencies.

INTRODUCTION

The task of improving aircraft safety for the low-level wind hazard takes two forms:

- 1) Detection and avoidance;
- 2) Enhanced survivability.

The approaches emphasized for survivability have been:

- Pilot training and procedures;
- Airframe/engine capability;
- Displays and annunciations.

Another approach that currently receives less emphasis than the others, but which offers greater potential, is the use of automatic systems, both coupled systems, which control aircraft motion unassisted, and director systems, to provide commands which the pilot controls.

Simulations of low-level shear hazards that have been associated with major incidents have confirmed the marginal ability or inability of pilots to cope with the hazard. Yet, the same simulations are used to demonstrate the high capability of automatic systems not only to survive the hazard, but to maintain precision tracking. Too often, major incidents occur after the pilot has turned off his automatic system, either by choice or by requirement.

Automatic systems have the ability to receive and quickly process large amounts of data simultaneously, and, thereby provide much quicker detection and reaction to a wind hazard than a pilot. The time to detect and react is frequently more important than the magnitude of the control applied. The longer the detection/reaction time, the greater the magnitude of the control required.

On the other hand, the pilot frequently has advantages of:

- Greater control authority and rate capability;
- Flexibility and adaptability;
- Less susceptibility to hazardous reaction to failures;
- Access to more controls, particularly secondary controls.

The advantages the pilot has over automatic systems are generally not inherent; the technology required to reduce or eliminate these advantages is available. Enabling the application of, or creating the demand for, this technology is the challenge.

In the following, the available technology and other potential means and needs for enhancing the capability of automatic systems to cope with wind hazards are discussed qualitatively.

CONTROL ALGORITHMS

At one time, the unavailability of quality sensors and computational capability for a reasonable amount of analog hardware restricted control algorithms to little more than a raw error signal operated on by a proportional gain, integral control and gain, and perhaps a rate damping term. A few gains dictated all aspects of automatic control; stability, tracking performance, activity in response to sensor noise and disturbances, and response to commands. Development of the control algorithms was more an exercise of seeking the best compromise. Sometimes filtering was added to reduce the effect of high-frequency activity from noise and disturbances, thereby permitting higher gains, but the tracking performance from the higher gains was largely offset by the adverse effect filtering had on stability and performance. Any increase in performance had an attendant increase in disconcerting activity and a tendency towards limit cycling due to rate saturation. The most important feature of the automatic mode, particularly speed control modes (by elevator or throttle) operating in a changing wind environment, may well have been the disconnect buttons or, at least, those buttons that revert to pitch and roll altitude command modes and allow the pilots to be the outer loop algorithms. Not only was there a hesitancy to seek higher levels of tracking performance for the variable wind environment (a fruitless exercise since the pilot would disengage the system due to the high level of attendant non-productive activity), there were overt attempts to degrade performance for the more severe wind environment so that the non-productive activity would remain within acceptable bounds (the "TURB" button).

The introduction of the digital computer has provided a tremendous computational capability. Combined with the new generation of high-accuracy, low-noise digital sensors, especially strap-down inertial sensors, a new architecture for control algorithms has been enabled.

- The former error signals can be split into the target and feedback components, which are processed separately before combining to form new error signals.
- The targets can be processed linearly and non-linearly to shape and control target acquisition without affecting stability and response to noise and disturbances.

- The feedback signals can be blended with inertial data to provide a signal having the static accuracy of the raw feedback signal and the low-noise, high-dynamic accuracy of the inertial signal without significant effects on stability and tracking performance. This blending can include the removal of sensor location effects resulting from coupling with angular motion.
- Comparison of air data and inertial data can be performed to derive wind components and their derivatives which can then be processed linearly and non-linearly before re-introduction into the feedback signal. This allows a high degree of independence between response to shear, response to turbulence, still air tracking performance, and stability.
- The derived wind components can be used for predictive control corrections that are applied as the wind disturbance occurs, but before feedback signal disturbances, thereby preventing the signal disturbances.
- The derived wind signals can be used predictively to remove the deterministic "noisy" responses of inertial signals to turbulence.

The result of applying these and other techniques is a much higher level of tracking performance for the previous level of unproductive activity. The feedback gains for attitude and path control functions can now be increased to the stability limits with virtually no increase in activity due to turbulence and no adverse effect on target capture performance.

For modes that control airplane motion relative to the air mass, principally airspeed modes, the trade-off between performance activity remains, though weaker and with much better performance for the same activity. This is principally due to the still imperfect inability to distinguish between the wind speed changes that will continue (shear?) and those that abruptly change (turbulence?).

The development of these modern control algorithms to maximize tracking performances in winds with acceptable activity and good maneuvering characteristics, required to gain the pilots trust and acceptance, does not come cheaply, quickly, nor without high technical risks. They, therefore, tend to be applied for terminal area modes only where required, specifically for Category III automatic landing, where the regulations on touchdown dispersions and airspeed control in winds are very stringent.

The availability of Category III automatic landing systems is limited principally to commercial transports. They are not used extensively for long-range aircraft due to the need for the pilot and co-pilot to perform a minimum number of manual landings each month to maintain their proficiency and to the limited number of landings available.

Category I and II automatic approach systems do not require tracking as tight nor do they require autothrottles. Hence, the survivability they provide in severe winds is not as good.

When coupled go-around modes are provided, they frequently do not provide closed-loop speed and path control, but only assure positive acceleration and vertical speed for a range of weights and thrust in still air. Go-around flight director modes may consist of nothing more than a fixed-pitch attitude command.

Coupled takeoff modes are not provided at all, even though an airplane fully equipped for a Category III-B automatic landing is also equipped to perform a "Category III-B automatic takeoff", if regulations existed to cover such a mode. One argument against such a mode is the lack of airports equipped with localizer deviation or the equivalent to enable steering down the runway for takeoffs. A similar argument was used against Category III-B automatic landings. Coincidentally, when the latest commercial aircraft were being developed with Category III-B automatic landing capability as standard equipment, there was an explosion in the number of Category III-B certified airports in the U.S.

Like the go-around function, the automatic takeoff pitch control function is essentially a speed control task. By controlling speed, thrust in excess of that required for level flight is converted to vertical speed. Complexity may be added to prevent selecting too low a speed (by estimating the equivalent of a minimum speed using angle of attack, inertial data, and configuration sensors) and to force a thrust deficiency to cause a speed reduction rather than a loss of altitude. Additional complexity is needed for the takeoff flight director to accommodate the pilot's rotation without over-shooting the attitude required for stabilized speed.

By employing airspeed and vertical speed blended with inertial data and inertial acceleration, speed control through pitch control can counteract the effects of variable winds. However, many takeoff flight directors provide nothing more than a fixed-pitch attitude command for all conditions. Even proposed advanced concepts plan to pre-compute a fixed-pitch attitude command based on pilot-entered weight, expected thrust, configuration, and ambient pressure and temperature. This attitude command would then result in the correct climb-out airspeed when controlled, but only in still air.

Takeoff autothrottles rapidly advance thrust to a selected setting, then disengage during the ground run at a predetermined airspeed so as to protect against a failure that could cause a thrust reduction. Whenever excess field length exists for the available thrust, the choice is invariably made to reduce the thrust setting so as to save engine life rather than to use all the thrust to accelerate to a higher rotation and climb-out in order to increase climb capability and speed margins. With the autothrottle inhibited from engagement, it does not attempt to detect an energy deficiency, as may occur in variable winds, and then advance thrust to the maximum available.

CONTROL AUTHORITY AND FAILURE PROTECTION

The classic method of preventing a failure that could cause an automatic system to command so much control surface so as to cause structural failure or a dangerous maneuver is to limit the control surface that can be commanded to a "safe" maneuver level. This limiting is achieved by servo displacement limits or by limiting the force or torque the servo can produce against the force or torque from the surface hinge moments or the control feel unit. The problem with this technique is that it also limits the control authority available to a non-failed system to counteract the effects of severe disturbances.

The "fail-safe" maneuver becomes excessive for operation near the ground, yet the control authority required at low speeds, even in still air, may easily exceed the fail-safe limits. Hence, for a Category III automatic landing system, two or more systems, each with their own servos, are used with their limited authorities summed to increase control authority when the multiple systems work together. When one system fails, the good systems counteract the failed system's command.

The control authority available from simultaneous multiple automatic systems is seldom provided for other than automatic landing systems and even then may not match the capability of the pilot. An aircraft equipped with a Category III automatic landing system is equipped to provide multiple system operation for all flight phases; therefore, it enhances survivability in severe winds. The additional expense is associated with much more testing and is substantial.

Most aircraft, especially smaller aircraft, are not equipped for Category III automatic landings because of the high cost, weight, and power consumption of the redundant equipment.

Digital computers have enabled an alternative approach--the self-monitored system. The processing capability is used to analytically detect failures in sensors, servos, and within the processor itself. This approach can eliminate the need for multiple servos for fail passivity and authority limiting fail safety, but the development and testing of the monitors required is very extensive and expensive.

The monitoring approach can also be used to raise low rate limits applied to protect against oscillatory failure and flutter coupling. These low-rate limits not only prevent the control command from keeping up with the disturbance, but, when saturated, can also cause a biased target or unstable limit cycling.

Pitch control authority can be further enhanced by quickening the trim response to trim command and increasing trim rate. Trim motion is typically delayed in response to a trim command all the time in order to prevent the trim from increasing the maneuver response to a hardover failure before a pilot reacts to the fault. Failure monitoring can eliminate the requirement for the delay. The trim rate available to the automatic system is typically half or less than that available to the pilot, although there is no failure requirement to force this disparity.

The subject of authority also includes lift. Some automatic functions are designed to prevent the attainment of additional lift near stall that might otherwise be used to prevent loss of altitude in a severe wind hazard. Systems that are allowed to operate near stall must be disconnected upon the onset of stall in order to prevent the natural automatic control reaction that is opposite to that required for stall recovery. To enable the additional lift near stall to be available, a very high accuracy and performance control algorithm is required to prevent stall, yet not interfere with very near-stall lift attainment.

INCENTIVE/DISINCENTIVE

The major challenge of enhancing safety for wind hazard, no matter what the means, is enabling the application of technology. This is a matter of creating incentives, eliminating disincentives, or creating disincentives for not enhancing safety. Sources of these incentive/disincentives are interrelated and include:

- Regulations
- Competition
- Economics
- Education

For the most part, regulations address disincentive. They don't say how a characteristic must be achieved, although FAA advisory circulars tend to promote methodologies by describing acceptable approaches, but describe what minimum characteristics an aircraft must have before it can be sold and what requirements optional functions must have. Regulations principally address safety and truth of advertising (satisfaction of intended function).

There's little doubt that the regulations governing automatic landing systems are responsible for the relatively high levels of performance of these systems in variable winds, although the homogeneous boundary-layer wind and turbulence models suggested may be lacking in accuracy and severity. Perhaps more important than updating these models is the application of similar treatment to other terminal area automatic modes.

Except for the automatic landing system, there is no quantitative minimum requirement for wind hazard survivability. Wind and turbulence models for automatic landing system simulation are analytic and parameterized. Minimum requirements are specified in terms of tower wind component levels and variation of horizontal wind with altitude. Minimum requirements are low and aircraft manufacturers usually seek certification to higher wind levels to enable automatic landings for more conditions. The test, however, is against the objective certification level. Seldom are efforts made to determine the maximum level of wind hazard the system is capable of surviving. There are no requirements for simulation demonstration of survivability in the severe non-homogeneous wind disturbances such as microbursts and storm fronts, although aircraft manufacturers do test these systems in simulations of these severe hazards.

An obvious question arises: Should regulations require minimum wind hazard flight control survivability, at least for terminal area operation? Requirements do exist for structural survivability. Such requirements would involve specification of the wind hazard model and a means for measuring success. The requirement should not specifically address automatic systems, rather automatic systems would be one of several means for showing compliance. Capability in excess of the minimum requirements could be rated; then this rating, similar to the automobile's estimated miles per gallon, could be a means for spurring competition and increasing awareness.

Part of the incentive for providing automatic systems is lost because regulations have two standards for manually and automatically controlled flight, and because they do not give credit for the superior performance of the automatic system. For example, although an automatic landing system may clearly demonstrate greater survivability in a wind shear hazard than manual flying, that same automatic system will likely be certified to conduct automatic landings in wind conditions less severe than is the pilot. This is because manual landing capability and performance are not based on the same strict standards that apply to automatic landing systems. Additionally, though approach airspeeds are not increased for increased wind severity for automatic landing systems as they normally are for manual flying, and though an automatic system may demonstrate much less likelihood of touching down long than a pilot, the field length requirements are the same for

both. Field length requirements don't even reflect the tendency for manual landings to touch down at higher speeds for more severe winds.

New automatic systems tend to be introduced only at the same time as new aircraft with a short development cycle, although additional features may be added to an existing aircraft. This is the worst possible time to aggressively seek the large potential benefits that entail technical and program risks. There is great pressure to reduce goals and assure that a system with lesser capability works well; the superior characteristics of an automatic system will not likely sell airplanes, but the inferior characteristics might prevent airplanes from being sold. A high-performance automatic system requires good detail models of aerodynamics, the control system, and sensors. New program pressures and the concurrent development of the airplane configuration, control system, and sensors prohibit that detailed modeling.

The best time to develop or, at least, evolve a high-performance automatic system is after an airplane is in production. If the evolution takes place, there is less need to make large technological advances during the development of the next new airplane.

The difficulty is convincing the customer he needs a new automatic system when his present one is performing adequately, particularly if the purpose is to enhance safety for what is perceived as an extremely remote event.

There is also a major role for education to play in eliminating disincentive. The pilot must be convinced that the severe wind hazard he could not cope with on the simulator is real, not an artificial contrivance, even though he never has and likely never will experience a similar hazard in flight. The pilots and airline passengers must be educated that attitude changes and engine modulations are indicative of tight control necessary to insure safety in the event that the change in wind experienced persists or subsequently changes more violently.

QUESTION:

Do you think that a realistic goal would be certification requirements for the design of the airplane and systems that are compatible with the airplane's performance?

RESPONSE:

I think the certification requirements of the automatic system are quite precise, and that is probably more of a standard, although it's a very exhaustive and expensive certification to go through. I guess what I was implying is that they talk about the airplane's capability, but when they measure the airplane's capability, it is actually an airplane/pilot capability. If you force the airplane pilot to go through the same kind of standards, then you probably would see a disparity and would come up with different conclusions as to what the capabilities were.

QUESTION:

Could the logic of the system be designed such that it will extract the maximum performance of the airplane through a given encounter?

RESPONSE:

Unfortunately, there are two sides to the story. You always pay for something that you get, particularly in the performance area, and particularly in speed-control modes, which is your principal means for counteracting. That is, under benign conditions, you may have more activity. Generally, the higher performance you get, the higher the activity, and you will be pressured to make sure that you are providing very good characteristics for the still-air environment, even if it means sacrificing for the more severe. I say part of that is going to come out of education, and maybe part of that comes out of our regulations. It's going to take somewhat of a change of attitude.